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MODELING OBSTACLES AND ENGINEER FORCES IN STOCHASTIC JOINT THEATER MODELS

by

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MODELING OBSTACLES AND ENGINEER FORCES IN STOCHASTIC JOINT THEATER MODELS

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This study proposes a methodology for modeling obstacles and combat engineer forces in a stochastic joint theater level model. The Joint Warfare Analysis Experimental Prototype (JWAEP) model serves as the host model for implementing this methodology. The methods presented in this research allow for the representation of combat engineer units and obstacles at the low level of resolution appropriate for a theater level model. Essential tasks in the engineer functional area of countermobility are modeled using engineer unit structures. An obstacle complex structure is presented and used to represent aggregations of tactical obstacles, similar to the obstacle zone and belt operational control measures used in US Army doctrine. This research also describes the attrition and delay algorithms for unit encounters with an obstacle complex and explains when this explicit attrition and delay are used.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Given the lethality of weapons on the modern battlefield, the effects of terrain and obstacles on a maneuver unit must be properly represented in a combat simulation model. This study proposes a methodology for modeling combat engineer forces and obstacles in a stochastic joint theater level model. The Joint Warfare Analysis Experimental Prototype (JWAEP) model serves as the host model for implementing this methodology. The methods presented in this research allow for the representation of combat engineer units and obstacles at the low level of resolution appropriate for a theater level model.

Essential tasks in the engineer functional area of countermobility, such as emplacing a minefield or anti-tank ditch, are modeled using engineer unit structures. The types and quantities of engineer equipment in a unit are used to represent the way in which engineer forces accomplish missions in their functional areas. These structures enable the model to represent engineer activities and their impact on unit movement over the battlefield.

Tactical obstacles are also modeled. An obstacle complex structure is presented and used to represent aggregations of tactical obstacles, similar to the obstacle zone and belt operational control measures used in US Army doctrine. Additionally, these obstacle structures are designed so that they are at a comparable level of resolution with combat units. Both of these structures efficiently capture the essential characteristics necessary in a theater level model, without causing unacceptable increases in memory or computing requirements.

This research also describes the attrition and delay algorithms for unit encounters with an obstacle complex and explains the situations when this explicit attrition and delay are used. It also introduces engineer strength parameters that the model uses in its decision making logic.

This research is unlike other research in this area for several reasons. Unlike earlier modeling efforts in the engineer community, this approach does not attempt to nest a high resolution engineer module within a low resolution theater level model. Instead, it uses the minimal essential elements necessary to captures the effect of engineers and obstacles on the battlefield. This research is also unique in its object oriented approach for representing obstacle complex structures. Some theater level models ignore the effects of tactical obstacles all together because of the aggregated unit and individual obstacle resolution mismatch. Other theater level models represent tactical obstacles as part of the existing battlefield, terrain or network. This method forces model designers to use a dynamic battlefield that changes frequently or periodically throughout the course of a simulation. A frequent battlefield update cycle causes an enormous increase in computing requirements, whereas a less frequent update cycle causes some loss in realism between unit and obstacle interactions. The object oriented obstacle structures in this research are not a part of the existing network. This permits scenario developers to quickly build and place obstacle complex structures anywhere on the existing battlefield or network. Additionally, unit and obstacle encounters are resolved separately so there is no need for a dynamic network or update cycle.

I. INTRODUCTION

A. GENERAL

Combat engineers perform numerous functions over several levels on the battlefield. They adapt terrain to multiply the battle effectiveness of fire and maneuver [Ref. 1]. Combat engineers provide support in many ways. In offensive operations, they are able to overcome a variety of obstacles and contribute to the offensive mobility of their supported maneuver unit. In defensive operations, they can impede enemy progress with mines and other obstacles on critical avenues of approach, as well as prepare fighting and protective positions.

Given the lethality of weapons on the modern battlefield, the effects of terrain and obstacles on a maneuver unit must be properly represented in a combat simulation model. The objective of this thesis is to propose a methodology for representing obstacles and combat engineer units, and the tactics employed for selected engineer tasks at a resolution appropriate for theater level combat. This methodology is demonstrated in the Joint Warfare Analysis Experimental Prototype (JWAEP) model.

B. JOINT WARFARE ANALYSIS EXPERIMENTAL PROTOTYPE (JWAEP)

The Joint Warfare Analysis Experimental Prototype (JWAEP) is an interactive, 2-sided, theater level combat simulation model based on an arc-node network representation of ground, air, and littoral combat. It is an experimental software prototype developed by the Naval Postgraduate School for research and experimentation into stochastic and command, control, communication, and intelligence (C^3I) centered approaches to modeling theater-level combat. The model is written in SIMSCRIPT II.5 according to the United States Air Force (USAF) THUNDER coding standard. The level of detail used in the model is appropriate for battalion to brigade-sized maneuver units [Ref. 2].

C. PROBLEM DESCRIPTION

The current version of the model, JWAEP version 1.2, does not support obstacle play other than representing classes of terrain that occur on the network. This structure basically captures terrain that is a natural or existing obstacle for a particular scenario. Every arc and node in the network has an associated characteristic for one terrain type. Figure 1 illustrates the SIMSCRIPT data file for the six terrain types represented in the JWAEP version 1.2 (JWAEP1.2). Terrain type is homogeneous over the entire area of a particular arc or node. Once selected, this terrain type is fixed throughout the simulation.

```
@       access  1 = ground units only      2 = naval units only
TYPE.TERRAIN
NUMBER.OF.TERRAIN.TYPES: 6
...ID...NAME.........COLOR.INDEX....ACCESS
  1    "Flat"             7              1
  2    "Rough"            8              1
  3    "Mountain"         9              1
  4    "Urban"           10              1
  5    "DMZ"             11              1
  6    "Sea"              5              2
END.TERRAIN.TYPES
```

Figure 1. Terrain types in JWAEP 1.2

Therefore, unit movements or battles have no effect on subsequent activities occurring on the network. The model also uses terrain categories to determine several parameter values such as opposed and unopposed movement rates and unit formation geometry.

JWAEP also does not explicitly represent engineers nor any of their primary functional areas: mobility, countermobility, survivability, sustainment (general) engineering, and topographic engineering. Both man-made (reinforcing) and natural (existing) obstacles have a profound effect on unit movement, especially when combined with the synergistic effects of indirect and direct covering fires. For example, a minefield may slow a unit's speed of advance, making it more susceptible to target acquisition and increasing its exposure to lethal enemy fires. Forces not capable of overcoming or

minimizing the effects of obstacles will incur higher casualties and be less effective on the battlefield. As JWAEP development progresses and matures, modeling the effects of obstacles and the tactics employed to overcome them is a vital aspect in accurately simulating the battlefield.

D. SCOPE OF THESIS

The primary emphasis of this research is to develop the methodology for modeling obstacles and engineer forces that may be tested in the JWAEP model. This research focuses on the essential and pertinent aspects necessary to portray engineers and obstacles at the theater level. This method avoids representing unnecessary aspects that tend to increase the resolution of a model and cause unacceptable increases in memory and computing requirements.

Combat engineers perform numerous functions over several levels on the battlefield. Engineer units can range in size from small specialized teams to large engineer commands. This thesis concentrates on the engineer functional area of countermobility, which means restricting the movement of an opposing force. The focus of this work is to identify US Army ground engineer forces that are organic to a division and other select forces at the corps level that provide a significant amount of countermobility assets in a theater. These engineer units are explicitly represented as well as the countermobility functions they perform most often in support of a maneuver brigade. Explicit representation means that most aspects of the engineer operation such as a particular engineer unit, its movement, and task performance are recognizable and present in the model. The methods used in this thesis are applicable for any conventional forces, even though the example for all of the model development is based on US doctrine and forces.

The obstacle structures in JWAEP must be at a comparable level of aggregation with combat units in order to adequately capture their interactions. Theater level models typically use maneuver brigades as the highest unit resolution. Therefore, obstacle

structures must also be aggregated at a commensurate level. This research defines a new class of data structures for representing tactical obstacles, such as minefields, and aggregations of these obstacles. It also describes the way in which engineer units emplacement these obstacles.

This research models selected actions employed upon encountering obstacles, and develops an algorithms for force attrition and delay. It also defines countermobility strength variables and uses these variables in the logic proposed for allocating the obstacle emplacement capability of engineer forces in general support of maneuver units. The emphasis for making these improvements is to model tactical obstacles and the effect of engineer forces on the battlefield while retaining the low resolution appropriate for a theater level combat model.

E. SUMMARY OF CONTENTS

This thesis consists of five chapters with the intent of giving the reader a thorough understanding of the engineer and obstacle structures required for implementation in JWAEP, a method for representing the engineer functional area of countermobility, and the explicit obstacle attrition and delay algorithms. This chapter presents the purpose, problem description, and scope of the thesis.

Chapter II includes a literature review that describes other theater level models. It also discusses the US Army Engineer modeling efforts. As an aid to the reader, the engineer functions, terms and definitions relevant to this research are defined and discussed in this chapter. Chapter III provides the methodology for representing engineer units and obstacles in JWAEP and discusses how the functional area of countermobility is modeled using these structures. Chapter IV discusses the logic for unit and obstacle interactions. It explains the close combat attrition present in JWAEP. Explanations are provided for the different unit tactics for obstacle encounters and the logic for an obstacle attrition and delay algorithm. Engineer strength parameters are also defined and discussed

as a method for implementing decision making logic in the model. The countermobility strength parameter is used to demonstrate a method for allocating engineer countermobility support on the battlefield. Chapter V discusses the conclusions of this research. It also provides recommendations for the future work necessary to implement the remaining engineer functional areas in JWAEP.

II. BACKGROUND

A. LITERATURE REVIEW

There are many combat simulation models in existence today. The level of detail varies from extremely high to low resolution. A high level of resolution corresponds to a low level of aggregation of forces in the model, whereas as low resolution implies a high level of aggregation. For example, a high resolution combat model may simulate individual soldiers over a few hours of combat for a platoon or company sized force. On the other hand, a low resolution model might simulate many maneuver brigades for several days of combat.

The focus of this literature review is on low (to medium) resolution models. These models are most similar to JWAEP and provide a good reference for how others have modeled terrain, obstacles, and/or engineer forces.

1. Concepts Evaluation Model

The Concepts Evaluation Model (CEM) is a fully automated, deterministic combat simulation that can simulate months of theater land and air combat in just a few hours on a computer [Ref. 3]. The US Army Concepts Analysis Agency (USACAA) uses CEM extensively in support of studies on force structure, materiel requirements, and combat force capabilities. These studies may simulate theater wars of up to 180 days duration at a low resolution.

According to CEM VI documentation, the model uses a simplified representation of the battlefield. Obstacles, and the tactics employed to overcome them, are not represented in any detail. The model's minimum distance resolution is one-tenth of a kilometer. Force movements are constrained within minisectors. Terrain, urban areas, and other factors that affect the movement of forces are represented by expanding or

contracting a minisector's width. This means that a constant size force, such as an armor brigade, will have a higher density of forces in a narrow minisector and a lower density of forces where the minisector is wide.

CEM divides the terrain into four types: types A, B, C, and D. The first three types reflect the general nature or lay of the land. For example, Type A is flat to gently rolling terrain with a minimum amount of timber. The fourth type of terrain, Type D, is intended to represent some major obstacle that would normally require extra or special effort for forces to negotiate. It may be anything from a river, lake, or canyon to a man-made barrier, such as a minefield. In order for terrain to be identified as Type D, it must extend across the battle area far enough to affect more than a division front. Additionally, the successful crossing of a Type D barrier is assumed to consume the major portion of a division period of 12 hours [Ref. 3: p.1-5]. This extremely low resolution severely limits any representation of tactical obstacles lower than the division level.

2. Vector-In-Commander

Vector-In-Commander (VIC) is a two-sided, deterministic simulation of combat in a combined-arms environment designed specifically to study the US Army's Airland Battle concepts in a variety of scenarios. VIC represents the major elements of land and air forces at the US Army corps level in a mid-intensity battle. According to Army Regulation 5-11, VIC is used to design force structures and develop concepts, doctrine, and tactics for brigades, divisions, and corps; determine corps/division resource requirements for sustained combat operations, and study material and item systems that are organic to, or have a profound influence on, the capabilities of brigades, divisions, or corps [Ref. 4: p. 7].

The battlefield in VIC is represented by a rectangular array of "grid squares". Each grid square has a specific relief classification (e.g., flat plains, rolling plains, rolling hills, hills, or mountains) and vegetation classification (e.g., dense forestation, sparse

forestation, grassland, or urban area). Each grid square is input in VIC as a sort of "picture map" using keyboard symbols for each type of classification. Scenarios, a collection of many grid squares, are developed from high-resolution digital data or map sheets. Although the grid square size is actually an input parameter, a 4 kilometer (km) grid is used in almost all of VIC scenarios. This 4 km grid is also used as an underlying assumption in the decision logic for several algorithms. Model users should assume terrain and vegetation to be no better than this resolution, no matter what grid square size is specified. Obstacles and engineer functions are well represented in VIC. The following section describes this representation.

B. ARMY ENGINEER COMMUNITY MODELING EFFORTS

The Engineer Model Improvement Program (EMIP) was established in 1989 as a comprehensive effort to insure that engineers are properly represented in the Army's land combat models. During the first phase of EMIP, the VIC simulation model became the focus for improvements in representing engineers on the battlefield. These improvements would result in VIC being able to serve as the first accredited engineer functional area model (EFAM) and provide the Army with a much improved analytic tool. The objective of this work was to ensure that VIC represents combat engineer operations well enough to allow analysts to accurately measure both the impact of changes in force structure on engineer capability and the contribution of engineers to the combined arms team. [Ref. 5: p. 29-40] Three areas of improvement in VIC were:

- a more complete representation of the types of tasks engineers perform, including adding task types not represented in VIC 2.0 and improving the manner in which individual tasks are generated.
- a new representation of engineer units, resources, and processes to allow a more accurate assessment of engineer capabilities.
- a more detailed representation of the terrain features altered by engineers and an improved representation of maneuver unit interactions with those features.

The EMIP identified several essential elements to include in the engineer module of VIC. It also establishes basic criteria for choosing the types of engineer tasks to model. The EMIP, as well as the resultant engineer module in VIC, provide excellent insight over the full spectrum of engineer activities on the battlefield.

As a result of this three-year program, engineer tasks, capabilities, and the terrain features altered by engineer forces are all well represented in VIC 5.0 (when the engineer module is running). Area obstacles (e.g., minefields) and linear obstacles (e.g., antitank ditches) are both present in the model. The obstacle complex, a model structure comprised of one or more area and/or linear obstacles, also allows for an aggregated representation of the effect of obstacles on a unit. Additionally, engineer functions on the battlefield are modeled explicitly whereas non-engineer units, capable of performing limited engineer functions independent of engineer support, are implicit. In essence, a high resolution simulation in the engineer module performs the necessary calculations, such as task duration and travel time, for all explicit activities. On the other hand, implicit activities are for the most part table look-up values.

This improved portrayal of the engineer function also adds a higher level of detail. The increased resolution found in the engineer module is an excellent tool for supporting the Engineer School's analysis work but is inconsistent and unnecessary when portraying a joint theater level war such as JWAEP. However, it does provide an important reference for constructing the methodology used in this thesis.

C. ENGINEER FUNCTIONS ON THE BATTLEFIELD

One must be familiar with engineer functions in order understand how and what to model in a simulation. The role of the engineer is best described in Army FM 5-100, Engineer Combat Operations. Engineers adapt terrain to multiply the battle effectiveness of fire and maneuver. This engineer component of the close combat triad (fire, maneuver, terrain) is described within the five engineer functional areas: mobility, countermobility,

survivability, sustainment engineering, and topographic engineering. To accomplish these functions, engineers serve throughout the theater, though the bulk of engineer forces are forward, within the close battle area [Ref. 1].

1. Mobility

Mobility frees the commander from movement limitations imposed by natural terrain or enemy action to allow maneuver of tactical units into positions of advantage. It includes all efforts required to allow the fighting force to move at will. Engineer terrain analysis and reconnaissance identifies the best route for movement, and engineers assigned to lead elements provide rapid, in-stride breaching of obstacles. Obstacles may be existing ones, such as a natural (river or mountain) and cultural (railway embankment or urban area) obstacles, or reinforcing ones (minefield or antitank ditch). The mobility function also includes construction of combat trails through areas where routes do not exist and the expedient development and/or repair of landing strips and forward arming and refueling points (FARPs).

2. Countermobility

Countermobility directly attacks the enemy commander's ability to execute his plan where and when he desires. It includes all efforts aimed a restricting enemy movement. Engineers emplace tactical obstacles to reduce the enemy's ability to maneuver, to increase his vulnerability to direct and indirect fires, and to protect friendly forces from counterattack. Tactical obstacles include minefields, destroyed bridges, antitank (AT) ditches, wire entanglements, abatis, and much more. Such obstacles may be employed individually or as components of an integrated obstacle system.

3. Survivability

Survivability allows friendly forces to fight from locations that would otherwise be untenable. It includes all efforts to protect personnel, weapons and supplies from exposure to both direct and indirect fire. Survivability focuses primarily on construction

of protective positions for combat vehicles, direct fire weapons, artillery and air defense systems, command and control elements, and critical logistics assets.

4. Sustainment Engineering

Sustainment engineering adds depth in space and time to the battle by ensuring that sustainment operations can occur. It includes all efforts required to sustain the fighting force. This includes replacing assault and tactical bridging with fixed bridging, clearing previously breached minefields and removing other obstacles, maintaining and improving lines of communication, constructing and repairing airfields and aircraft facilities, and constructing and repairing support facilities.

5. Topographic Engineering

Topographic engineering defines and delineates the terrain for planning and operations, and provides precise location data to modern efficient weapons systems. It includes terrain analysis, production of updated maps and overlays, and survey support for artillery and missile targeting requirements.

D. TASKS IN EACH ENGINEER FUNCTIONAL AREA

Many different tasks are performed by engineers on the battlefield. These tasks require a variety of engineer units depending on their magnitude and scale. The essential tasks to be modeled are categorized using the engineer functional areas listed below.

Countermobility:

- Emplace area obstacles (minefields)
- Emplace line obstacles

Mobility:

- Breach area obstacles (minefields)
- Breach line obstacles

Survivability:

- Prepare protective positions

Sustainment Engineering:

- Clear area obstacles (minefields)
- Improve line obstacle breaches
- Maintain roads

Topographic Engineering:

- Map Production
- Survey Support
- Terrain Analysis

This research only addresses the tasks listed under countermobility. Essential tasks in mobility and survivability should be considered as the JWAEP engineer functional module matures. Presently there is little use in modeling engineer tasks in the topographic engineering functional area. Tasks such as map production, survey support, and terrain analysis have little meaning when applied in the context of JWAEP.

E. TYPES OF OBSTACLES

An obstacle is any physical characteristic of the terrain which impedes the mobility of a force. Obstacles are grouped into two general categories: existing and reinforcing.

1. Existing Obstacles

Existing obstacles consist of any natural or cultural attributes of the terrain that impede a force's movement, such as heavily wooded or steep mountainous "no-go" terrain, population centers, elevated railways/roadways, and waterways. They are most often represented as part of the network attributes or terrain database in a combat simulation model.

2. Reinforcing Obstacles

Reinforcing obstacles are the second type of obstacles. These obstacles are placed on the battlefield as a result of military effort. They are specifically constructed, emplaced, or detonated by enemy or friendly forces. Reinforcing obstacles are often used to enhance the effect of an existing obstacle. A combat simulation model must be able to dynamically represent reinforcing obstacles in order to capture their effects on the battlefield. Reinforcing obstacles are further categorized as protective or tactical obstacles.

a. Protective Obstacles

Protective obstacles are used to protect a force from the enemy's final assault onto the force's position. They are close to defensive positions and are tied in with the final protective fire of the defending unit. Low resolution combat models usually account for protective obstacle effects by using higher attrition coefficients on attacking forces when the defender has been in place for sufficient time to emplace these obstacles. In essence, a detailed representation of protective obstacles is not present at this level.

b. Tactical Obstacles

Tactical obstacles are used to directly attack the enemy's ability to maneuver, mass, and reinforce in support of the force's direct and indirect fire plans and tactical movements. It is essential to capture the effects of these obstacles in a low resolution combat simulation model.

F. GENERAL CATEGORIES OF INDIVIDUAL TACTICAL OBSTACLES

There are four general categories of individual tactical obstacles. These are individual obstacles in obstacle groups, directed obstacles, reserve obstacles, and situational obstacles [Ref. 6: pp. 4-12, 4-13].

1. Individual Obstacles In Obstacle Groups

Individual obstacles in obstacle groups are tailored to the obstacle group effect (discussed in section G) and the threat. For example, minefield densities, composition, pattern, depth, and frontage have specific norms for achieving different effects.

2. Directed Obstacle

The second type of tactical obstacle is a directed obstacle. This obstacle is directed by a higher commander as a specified task to a subordinate unit. These obstacles, located in a subordinate unit's area of responsibility, are critical to the success of the directing unit's (e.g., higher headquarters) plan. A minefield, anti-tank ditch, or any other type of obstacle can be a directed obstacle.

3. Reserve Obstacle

A reserve obstacle is an obstacle for which the commander restricts the execution authority. The commander usually specifies the unit responsible for reserve obstacle emplacement, handover, and execution. The commander must also clearly identify the conditions under which the reserve obstacle is to be executed. For instance, a division commander may designate a bridge be prepared for demolition and restrict detonation until it is eminent that enemy forces are going to overtake the bridge.

4. Situational Obstacle

The fourth type of individual tactical obstacle is the situational obstacle. The situational obstacle is an obstacle emplacement capability held in reserve. Its execution is triggered by friendly and/or enemy actions. It is different from a reserve obstacle because it can be shifted to different locations, whereas the reserve obstacle is location specific. Situational obstacles must be carefully integrated in the plans of a maneuver unit in order to be executed effectively. The plan must identify trigger action and execution criteria at a specific decision point and contain necessary subunit instructions to emplace and cover the

obstacle. Air Force or artillery delivered scatterable mines are frequently planned as situational obstacles. For example, a commander in a defensive position may want to disrupt or turn the retreat of a repelled enemy attack with air delivered scatterable mines. The minefield is planned as a part of the defense, but its location is not specified until determining the direction of the enemy retreat.

G. TACTICAL OBSTACLE EFFECTS

Tactical obstacles can have one of four intended effects. They can disrupt, turn, fix, or block the enemy. An obstacle effect is conveyed through the use of precise graphics overlaid on a map. Each effect has an associated symbol that represents exactly how the enemy's maneuver should be altered. For instance, a turn symbol points in the desired direction the enemy formation should follow. Each effect also has a specific resourcing factor that helps determine the amount of linear tactical obstacle effort needed to achieve its desired effect [Ref. 7: p. 2-8]. Figure 2 provides an example for each of these symbols. As discussed in the next section, an effect can also be assigned to an obstacle zone but is required for obstacle belts and groups.

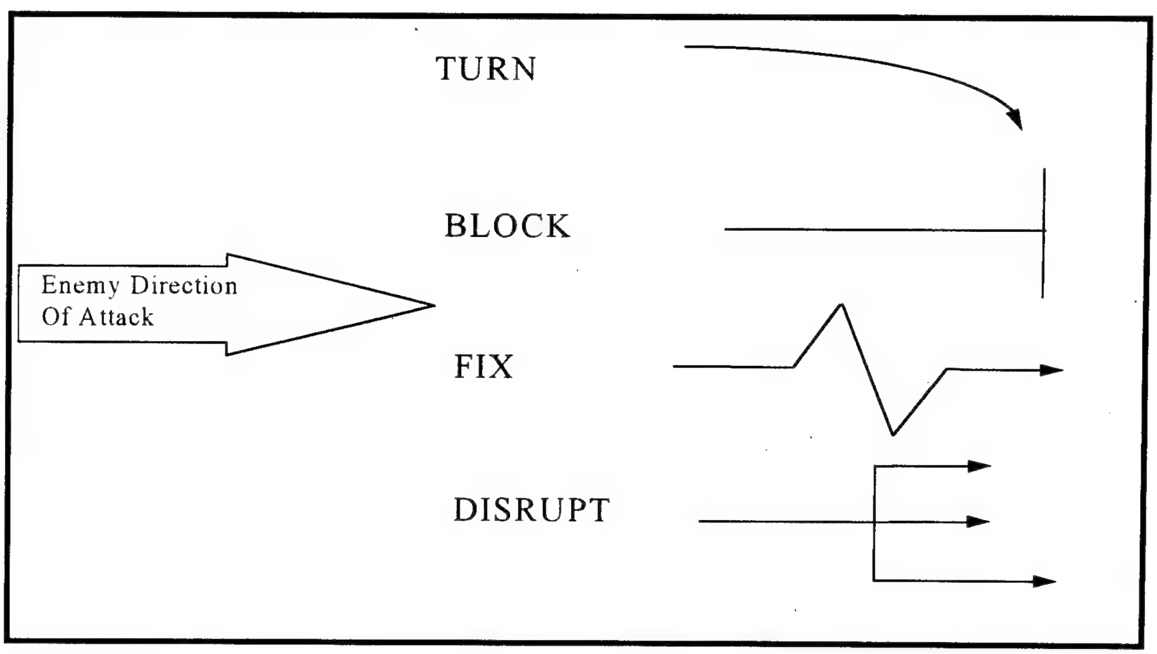

Figure 2. The Four Intended Effects Of Tactical Obstacles

H. TACTICAL OBSTACLE PLANNING AND CONTROL MEASURES

The challenge of a defending force is to strip away the enemy's initiative and create exploitable vulnerabilities. The synchronization of indirect and direct fires and tactical obstacle effects is crucial to being successful. Tactical obstacle planning occurs at division level and lower. Divisions, brigades, and battalion task forces plan obstacle zones, belts, and groups, respectively. These three obstacle control measures permit tactical obstacle placement and focus subordinate units on their particular obstacle plans. A commander may also provide an obstacle intent to subordinate units. An obstacle intent identifies the intended target (enemy force), the effect (disrupt, turn, fix, or block), and a relative location on the battlefield at which the intent is to occur. It essentially defines the end state that must be achieved by fires and obstacles for success. An obstacle intent is required for brigade and lower obstacle plans. An understanding of the principles and functions of obstacle zones, belts and groups is critical in order to model obstacles in a combat simulation.

1. Obstacle Zone

An obstacle zone is a graphic control measure used by divisions to designate an area in which subordinate brigades are authorized to emplace tactical obstacles. The division commander uses obstacle zones to control and focus the obstacle effort for subordinate units. The division's scheme of maneuver drives the shape and location of the obstacle zone. Obstacle zones are given to subordinate brigades and do not cross their individual boundaries. They usually cover a broad area in order to give subordinate brigade maximum flexibility in their planning. An obstacle intent is not normally assigned to an obstacle zone. Obstacle zones also drive the initial flow of obstacle materials to committed forces. Figure 3 shows the operational graphics for a division defensive area where three obstacle zones are planned. Note that the division zone restricts the two forward brigades from emplacing belts that could interfere with the division counterattack objective.

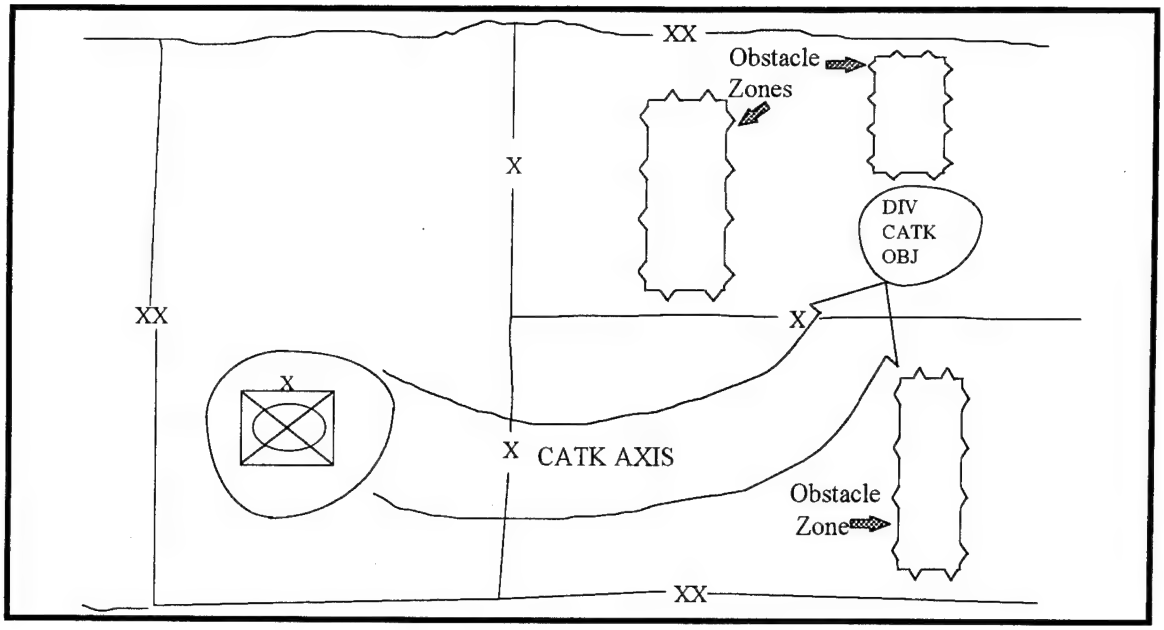

Figure 3. The Obstacle Zone Control Measure

2. Obstacle Belt

An obstacle belt is a graphic control measure used by brigades to designate an area within an approved obstacle zone in which subordinate units are authorized to emplace tactical obstacles. Obstacle belts must be inside obstacle zones, or be approved at division level. Obstacle belts focus and synchronize the brigade's obstacle effort. They generally straddle the enemy avenues of approach that are covered by the brigade's maneuver battalions. Each obstacle belt must have an intent. Tactical obstacles are only permitted within the confines of the obstacle belt. Figure 4 shows an expanded view of the Northern brigade sector in Figure 3. In this example the division has designated two obstacle zones in the brigade sector. The brigade has further defined obstacle belts (with intents) within each of these zones.

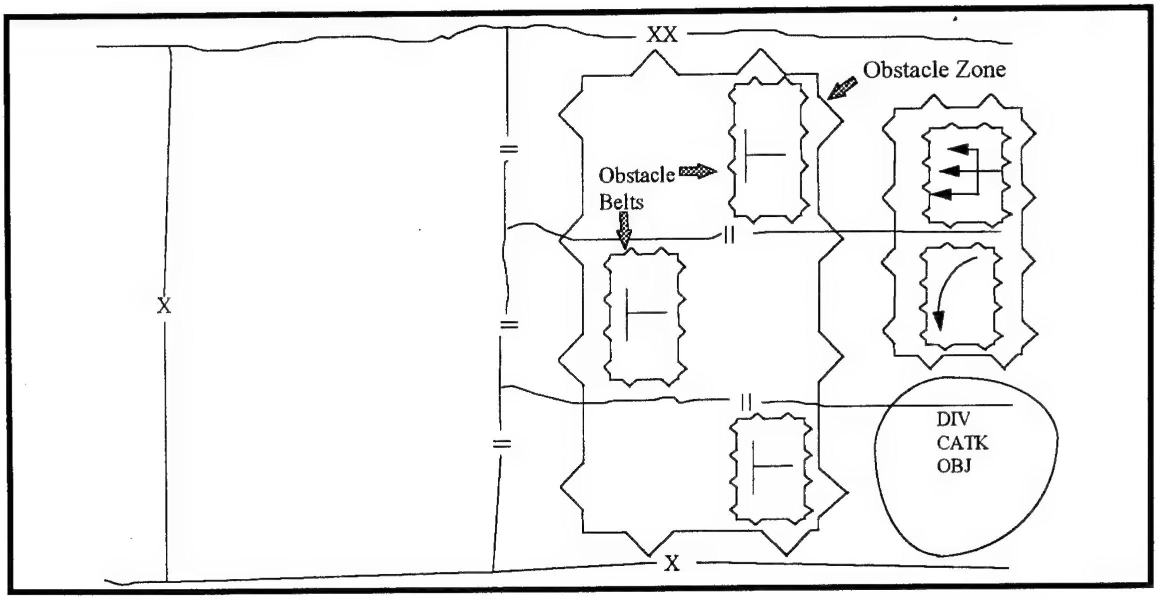

Figure 4. Obstacle Zones With Obstacle Belts And Intended Effects

3. Obstacle Group

An obstacle group is an array of individual tactical obstacles within an obstacle belt whose combined effect accomplishes a single obstacle intent. Obstacle groups must be inside an obstacle belt or approved at brigade level. Battalion task force commanders designate obstacle groups to integrate individual obstacles with direct and indirect fires. When more than one obstacle group is used within an obstacle belt, the sum effect of the groups must accomplish the intent of the obstacle belt. Obstacle groups are at a relatively high level of resolution in the context of a theater level simulation and are not modeled in this work. This description serves only to provide complete coverage of the obstacle planning and control measures from the division down to the battalion level.

III. METHODOLOGY FOR MODELING ENGINEERS AND OBSTACLES

A. REVIEW OF THE JWAEP ARCHITECTURE

A basic understanding of the JWAEP model architecture is essential before proposing a method for portraying engineer forces and obstacles. The most pertinent aspect is the way in which the object oriented programming structure used in the model represents combat units.

1. Combat Units

Combat units in JWAEP are defined by using basic building blocks found in the unit class data. The unit class data are used to provide information describing specific unit types, such as an armor brigade or mechanized infantry brigade, that exist in the model. These data describe items such as the unit Table of Organization and Equipment (TO&E), unit movement parameters, and unit formations. Multiple instances of these units are possible in a scenario, where each unit instance is drawn randomly from the unit type with a predetermined degree of variance. For example, an armor brigade instance may be initialized with only 95 percent personnel strength and 90 percent of its authorized tanks. Figure 5 provides two examples of a unit type definition as it appears in JWAEP1.2. In these examples, the type unit is defined by the unit class four-digit numbers 1002 and 1005. All instances of a unit with the same unit class number have identical types of equipment, in quantities that may differ by the numerical standard deviation shown.

2. Ground Equipment

The different types of ground equipment that may be included in each unit class type are defined in the *equipment.dat* file. This file details all of the different equipment types, with weapons, that are possible in any scenario. This file is related to other JWAEP files that link to the Attrition Calibration (ATCAL) data files used to calculate attrition. There are currently 123 equipment types available in JWAEP. Figure 6 contains an

example of the M1A1 equipment type. Each piece of equipment has a unique four-digit number followed by its name. Note that the M1A1 also has two numbered weapons, identification numbers (ID) 1101 and 1102, listed on this piece of equipment.

```
1002  "Armor Bde in Armor Div"
SIDE . .CLASS . .FUNCTION . .MAX.SUPPORT.RANGE . . .GROUP. AD.TYPE
 1      1001       1                50                1001      0
    EQUIPMENT
         ID . . . . .QTY . . . . .STD.DEV
         1110     116        10     (M1A1 Tank)
         1200     126        10     (M2 IFV)
         1210      12         2     (ITV)
         1230      16         4     (FISTV/GLLD)
         1275      54         9     (NonUS IFV-25MM)
         1500      12         1     (MLRS)
         1620      32         4     (120mm/4.2 Mortar)
         1800     888       100     (Blue Troops, personnel)
    END.EQUIPMENT
1005  "Inf Bde, Mech Div"
SIDE . .CLASS . .FUNCTION . .MAX.SUPPORT.RANGE . . .GROUP. AD.TYPE
 1      1002                        50                1002      0
    EQUIPMENT
         ID . . . . . QTY . . . . .STD.DEV
         1110     104        10     (M1A1 Tank)
         1200      54         9     (M2 IFV)
         1210      12         2     (ITVs)
         1230      18         5     (FSTV/GLLD)
         1275       7         1     (NonUS IFV-25MM)
         1520      24         5     (155 mm Howitzer)
         1600      20         4     (Stinger/Redeye)
         1620      18         2     (120mm/4.2 Mortar)
         1800    1784       200     (Blue Troops, personnel)
    END.EQUIPMENT
```

Figure 5. Unit Type Definitions

3. Weapons

Weapons are categorized and defined within the *equipment.dat* and *typeeq.dat* files. The *equipment.dat* file is a scenario specific file and is a subset of the *typeeq.dat* file. All weapons must be identified for both blue and red forces, even when a weapon is common to both forces. Figure 7 illustrates the format for this file. Note that each weapon is described by a four-digit ID, its parent equipment name, side, and the weight of a single round of ammunition.

```
1100 "M1A1"
SIDE . .CLASS . .CATEGORY . .TGT.TYPE . .STONS . .AD.SITE.TYPE . . .IMPORTANCE
 1        1          1           10001        60.0                    0                .80
       PALLETS . .SIZECAT . .LAPE%LOSS . .DROP%LOSS . . .PP.EQ.CAT
           2            3            10             40            10001
       WEAPONS . .ID . . .QTY
                   1101     1
                   1102     1
       END.WEAPONS
```

Figure 6. Equipment Type Definition

```
ID . . . . NAME . . . . . . . . . . . . . . SIDE . .LBS/ROUND
1101   "M1A1"                  1          62.63
1102   "M1A1"                  1           1.22
 .        .                    .             .
 .        .                    .             .
 .        .                    .             .
2101   "T72"                   2          62.63
2102   "T72"                   2           1.22
 .        .                    .             .
 .        .                    .             .
 .        .                    .             .
```

Figure 7. Weapon Types

4. Unit Instances

Instance data describe the specific qualities of a particular unit type. They relate all of the generic unit characteristics described above to a particular unit. Instance data also define all of the various units that are specific to a particular scenario in JWAEP. This input data file is called *units.dat*. This file contains every unit instance as well as the date

and location of its initiation into the scenario. An orders list for each unit instance is contained in the *coa.dat* file.

The first order always initializes a unit at a specific time and location in the scenario. From initialization forward, order times are relative to the order prior to it. Some possible orders include initialize, attack, defend, movement to contact, general support, and tactical assembly area. All orders provide a destination node and a delta time the unit waits before the order is executed. Orders that require unit movement can be prescribed explicitly or determined by an automatic path generator. For automatic paths, JWAEP uses a modified, least cost Dykstra's Algorithm. Figure 8 illustrates unit instances which are a part of a developmental North Korean major regional contingency (MRC) scenario. Each definition includes the unit's five-digit identification number, unit name, side, and unit type. Figure 9 illustrates possible order sets for the two units in Figure 8. The delta time parameter is common for every type of order. The remaining parameters depend on the type of order. For instance, unit number 10501 initializes at delta time 0.0 (the start of the scenario) on node 12. It next travels by the AUTO path generator to node 12 where it will defend for a period of 9999 decimal days, where 9999 is essentially infinite time in the model. The last parameter in the attack order is an override flag (YES = 1 and NO = 2) that allows the unit to ignore the model's force ratio rules. The model's default behavior is to follow force ratio rules, which include items such as attacking with a force ratio of at least three to one. Note that order set for unit 10501, the second order set in Figure 9, requires it to attack to node 24 along a user determined, manual path. It specifies the unit move along a path from node 14 to sequential nodes 18, 19, 22, and 24 (depicted by MANUAL 18 19 22 24 END.PATH).

```
10501           "Inf Bde, 2 Mx Div"
SIDE . .TYPE
  1      1005
11504           "ROK Inf Bde, 2 Mech Div"
SIDE . .TYPE
  1      1015
11805           "ROK 5th Inf Div"
SIDE . .TYPE
  1      1018
```

Figure 8. Sample Unit Instances

```
UNIT.ID
 10501
ORDERS
 DELTA.TIME. .TYPE
       0.0      INITIALIZE      1
       0.0      DEFEND          12  AUTO     2.0    9999  2
END.ORDERS

UNIT.ID
 11805
ORDERS
  DELTA.TIME. .TYPE
       0.0      INITIALIZE      14
       0.0      ATTACK          24  MANUAL 18 19 22 24 END.PATH  2.0    2
END.ORDERS
```

Figure 9. Sample Orders for Unit Instances

B. DECIDING WHAT ENGINEER FORCES TO MODEL

As mentioned previously, engineer forces operate over the entire spectrum of the battlefield. Modeling every conceivable type of engineer unit in a theater is neither practical nor feasible in a low resolution model. This work focuses on ground engineer forces organic to a division and select forces at the corps level that provide significant countermobility assets.

1. Divisional Engineer Units

The engineer units organic to a division vary according to the type of division they support. Table 1 illustrates this organization. The armored and mechanized infantry divisions, henceforth collectively referred to as armored divisions, have an organic engineer brigade consisting of three mechanized engineer battalions and a headquarters and headquarters detachment (HHD). Each battalion is habitually associated with one of the division's three ground maneuver brigades. The TO&E of these battalions is designed so that the vast majority of their support efforts are on mobility missions, and to a lesser extent countermobility, survivability, and sustainment engineering.

TYPE DIVISION	ORGANIC ENGR UNIT
Armored or Mechanized Infantry	Brigade
Light, Airborne, or Air Assault	Battalion

Table 1. Engineer Forces Organic to a Division

The engineer battalion organic to light, airborne, and air assault divisions is a more austere organization than the engineer brigade found in armored divisions. In general, no habitual relationship exists between engineer companies and maneuver brigades. Instead, this battalion provides support to the division by concentrating support where needed. The limited equipment assets present in these battalions only allow for short-term operations.

The engineer battalion in a light division provides extremely limited countermobility support or for any other engineer mission, especially when compared to its armored division counterpart. Therefore, modeling the engineer brigade found in armored divisions is the most significant division level engineer unit in this research.

2. Corps Level Engineer Units

A corps engineer brigade is responsible for all engineer units operating in the corps' and division's rear areas. The corps engineer brigade is a large, flexible organization containing up to three different types of combat engineer battalions as well as all of the specialized engineer units required to support corps operations. It does not have a predetermined number and/or type of units. Instead, it task organizes and tailors support based on the number and type of divisions (and their missions) assigned to the corps. The corps engineer brigade provides support to divisions for mobility missions such as bridging and large-scale breaching operations, intense countermobility and survivability missions associated with deliberate defenses, and many of the rear area sustainment engineering missions such as main supply route maintenance.[Ref. 6: pp. 1-5, 1-9] Table 2 lists the types of engineer units and missions that might be found in a notional corps engineer brigade supporting a four-division corps consisting of one light infantry division and three armored divisions. The primary and secondary missions listed for these units are based on each unit's TO&E and the author's experience in the area. Note that the corps wheeled engineer battalion is the only unit whose primary mission is countermobility. Similar to its armored division engineer battalion counterpart, the corps mechanized engineer battalion is primarily suited for mobility missions, but can perform a reasonable amount of countermobility when required. The corps light engineer battalion is not considered a major contributor for countermobility missions for the same reasons outlined above for their light division counterpart. Therefore, the corps level engineer units of primary interest in this research are the wheeled and mechanized engineer battalions. These two units provide the vast majority of the corps countermobility support to forward-positioned divisions.

CORPS UNIT AND SIZE	PRIMARY MISSION	SECONDARY MISSION
Mechanized Engr Bn	Mobility	Countermobility
Wheeled Engr Bn	Countermobility	Survivability
Light Engr Bn	Mobility	Countermobility
Combat Heavy Engr Bn	Sustainment Engineering	Survivability
Ribbon Bridge Co	Mobility	
Medium Girder Bridge (MGB) Co	Mobility	
Combat Support Equipment (CSE) Co	Sustainment Engineering	Survivability

Table 2. Notional Corps Engineer Brigade Support Units and Missions

3. Engineer Units Modeled

In summary, there are three engineer units in the division and corps area that provide substantial support for countermobility missions. These three units, the divisional engineer brigade, and corps wheeled and mechanized engineer battalions provide the vast majority of the ground countermobility assets available in theater. Structures for these units are developed in the next section. However, as the engineer functional module in JWAEP matures, similar structures may be developed to represent engineer functions such as mobility and survivability. These new missions may be performed by existing engineer units present in the model that are capable of performing them, or by defining additional units possessing these capabilities.

C. ENGINEER STRUCTURES IN JWAEP

1. Engineer Units

The engineer battalion is the lowest level organization to be represented in JWAEP. All three battalions of interest have similar organizations. Each battalion is composed of a headquarters and headquarters company (HHC) and three "line" companies. The three line companies possess the vast majority of engineer specific

equipment whereas the HHC provides most of the logistical and maintenance support. Figures 10 and 11 illustrate two examples of an engineer unit type definition.

```
1080 " Div Engr Bn in Armor or Mech Bde"
 SIDE . .CLASS . .FUNCTION . .MAX.SUPPORT.RANGE . . .GROUP. AD.TYPE
  1      1002       2                  30                1008      0
     EQUIPMENT
          ID . . .QTY . . . . .STD.DEV
          1240    29         5          (M113)
          1800   433        50          (Blue Troops, personnel)
          1900     6         1          (CEV)
          1901    12         2          (AVLB)
          1902    12         2          (M58A4 MICLIC)
          1903     6         1          (VOLCANO,5-ton truck mtd)
          1904    21         4          (M9 ACE)
          1905     6         1          (M128 GEMSS)

     END.EQUIPMENT
```

Figure 10. Unit Type Definition for a Divisional Engineer Battalion

```
1081 "Corps Wheeled Engr Bn"
 SIDE . .CLASS . .FUNCTION . .MAX.SUPPORT.RANGE . . .GROUP. AD.TYPE
  1      1002        2                 30                1008      0
     EQUIPMENT
          ID . . . . .QTY . . . . .STD.DEV
          1800     533        80        (Blue Troops, Personnel)
          1903       6         1        (VOLCANO,5-Ton Truck Mtd)
          1906      30         5        (D7 Bulldozer)
          1907       6         1        (Scoop Loader)
          1908      18         3        (SEE)
          1909      42         7        (M929 5-ton Dump Truck)
          1910      20         3        (5-Ton Cargo Truck)
          1911       9         2        (130G Road Grader)
          1912      10         2        (M916 Tractor Truck)
          1913      12         2        (40-Ton Low Bed Trailer)

     END.EQUIPMENT
```

Figure 11. Unit Type Definition for a Corps Wheeled Engineer Battalion

2. Engineer Equipment

The engineer equipment list represents all assets a unit has to accomplish engineer functional area missions. Similar to the *equipment.dat* file for combat units in JWAEP, all engineer specific equipment must be added to an "*engr.equipment.dat*" file. For the most part, this equipment will not have any weapon systems. Instead, engineer equipment will describe the rate in which it performs a task specific to a particular engineer function. For example, the D7 bulldozer is capable of digging an anti-tank ditch (AT ditch) at a rate of, say, 20 meters per hour in support of countermobility missions. Mine laying equipment, such as the VOLCANO, can be expressed in terms of mines per hour. Figure 12 illustrates some examples of the equipment used for countermobility missions.

3. Engineer Weapons

The engineer pieces of equipment that have weapons can simply be added to the *equipment.dat* file. It is important here to note the difference between a weapon on a piece of equipment and a piece of equipment that is capable of emplacing a "weapon". For example, the 5-ton truck mounted VOLCANO is a mine dispensing piece of equipment. It has absolutely no weapons, such as a machine gun, to attrite other forces but it does have a significant, attrition producing, mine laying capability. These types of equipment do not belong in the weapons file. They are represented in the *engr.equipment.dat* file where their capabilities are expressed in terms of a rate per unit time for a specific engineer function.

ID	NAME	SIDE	AT.MINES.HR	AP.MINES.HR	ATDITCH.HR
1900	"CEV"	1	0	0	10
1903	"VOLCANO,5-TonTrk"	1	800	160	0
1904	"M9 ACE"	1	0	0	15
1905	"M128 GEMSS"	1	800	800	0
1906	"D7 Bulldozer"	1	0	0	30
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
2900	"CEV"	2	0	0	10
2902	"GMZ Minelayer"	2	600	600	0
2904	"Armored Bulldozer"	2	0	0	15
2906	"Bulldozer"	2	0	0	25

Figure 12. Engineer Type Equipment Definition for Countermobility

4. Engineer Unit Instances

Engineer unit instances are very similar to combat unit instances. These can easily be added to the existing *units.dat* file. Orders for engineer unit instances may include direct support and general support missions for combat units. For instance, the engineer battalion that is organic to a divisional maneuver brigade typically has orders to initialize and then provide general support to their maneuver brigade. Figure 13 illustrates an engineer unit instance and order set for the 5th Mechanized Engineer Battalion of the 5th Mechanized Infantry Division (5th Inf Div (M)). Its orders are to initialize and provide direct support to the 5th Inf Div (M) for the entire scenario (9999 = infinite time). Similarly, a corps combat engineer battalion may have orders to provide general support from a particular node to any combat unit within its support range. Using this method, model users can create a robust scenario where engineer units provide differing support through several phases of a campaign.

```
UNIT.ID
 10801          "5th Mech Engr Bn, 5th Mech Inf Div"
        SIDE . .TYPE
          1       1028
UNIT.ID
 10801
    ORDERS
        DELTA.TIME. .. . . .TYPE
                0.0          INITIALIZE          12
                0.0          DIRECT SUPPORT   UNIT 2205   AUTO   2.0    9999
        END.ORDERS
```

Figure 13. Engineer Unit Instance and Orders

D. MODELING OBSTACLES IN A SIMULATION

To capture the interaction between a unit and an obstacle, there must be a proper level of aggregation for both entities. Theater level models typically use maneuver brigades as the highest unit resolution. A maneuver brigade can cover an area of 2 to 5 kilometers, whereas a single tactical obstacle can be as small as 50 to 100 meters. This size disparity makes it extremely difficult to describe the effect of obstacles on units and model doctrine for employing obstacles. It also complicates the job of a scenario developer and places a heavy burden on computer memory and processing time.

These problems can be overcome by representing aggregated obstacles in obstacle belts and zones. These aggregations were generically termed "obstacle complexes" by the Waterways Experiment Station (WES), US Army Corps of Engineers during the EMIP. [Ref. 8] Obstacle complexes can represent either belts or zones. Implementing obstacle complexes has several advantages:

- the level of aggregation of obstacles is consistent with the level of aggregation of combat forces,
- scenario development is simplified by eliminating the need to individually site and describe every obstacle,

- indirect and direct covering fires can be explicitly played,
- an increase in execution speed and a decrease in memory requirements result when compared to the individual obstacle representation method.

E. MODELING OBSTACLES IN JWAEP

Obstacles in JWAEP can be modeled several ways. The most efficient and flexible approach is to create an obstacle complex class of data structures which are very similar to that of a unit. This method has several advantages. For instance, the terrain representation on the network remains unchanged. If obstacles were represented as a new type of terrain feature, it would force the model to handle dynamic changes to the network during the simulation run time. This causes a tremendous increase in the number of computations required for each event, significantly increasing the overall simulation run time and memory requirements. Using this method also provides a logical, straight-forward way in which to handle the attrition and delay suffered when a unit encounters an obstacle complex.

The following paragraphs outline this structure from individual obstacle prototypes, the smallest level of representation, up to the obstacle complex structure.

1. Obstacle Prototypes

An individual obstacle exists as a user defined prototype. The number and type of obstacle prototypes are controlled by the model user. Several obstacle prototypes are established for realism when defining a scenario. Fields such as mine type, total mine density (per linear meter), frontage, and depth are specified in each prototype. A sample list of prototypes is shown in Figure 14. The block minefield prototype is completely defined in Figure 15.

```
OBSTACLE.PROTOTYPE
NUMBER.OF.OBSTACLE.PROTOTYPES: 7
..ID....NAME
801    "Block Minefield"
802    "Fix Minefield"
803     "Disrupt Minefield"
804     "Dummy Minefield"
805     "Concertina Wire "
806     "Anti-Tank Ditch"
807     "Demolished Bridge"
END.OBSTACLE.PROTOTYPES
```

Figure 14. Sample Obstacle Prototypes

```
1800 "Block Minefield"
SIDE....FRONTAGE....DEPTH...ATMINES....APMINES.......LINEAR.DENSITY
 1          500          320        550           84                    1.27
WEAPONS..ID...................NAME.............QTY...........
            1810          "M21 AT Mine"    550
            1811          "M16 AP Mine"     84
UNOPPOSED.EMPLACEMENT.COMPLETION.RATE
  UNIT.SIZE:  1001
     UNIT.CATEGORY:  1005
        TERRAIN.TYPE..........RATE.MULTIPLIER........RESTRICTION
                1                    1.00                    1
                2                    0.70                    1
                3                    0.60                    1
                4                    0.50                    1
                5                    0.50.                   1
                6                    0.00                    2
END.UNOPPOSED.EMPLACEMENT.COMPLETION.RATE
OPPOSED.EMPLACEMENT.COMPLETION.RATE
  UNIT.SIZE:  1001
     UNIT.CATEGORY:  1005
        TERRAIN.TYPE...........RATE.MULTIPLIER........RESTRICTION
                1                    0.00                    1
                2                    0.00                    1
                3                    0.00                    1
                4                    0.00                    1
                5                    0.00.                   1
                6                    0.00                    2
END.OPPOSED.EMPLACEMENT.COMPLETION.RATE
```

Figure 15. Antitank Minefield Prototype

The block minefield prototype in Figure 15 provides information on the frontage, depth, and composition of the minefield. It also provides unopposed and opposed completion rates for each unit size and category for various types of terrain. The total time it takes to emplace a prototype depends on the particular type of engineer equipment used and the rate at which it is slowed due to terrain. The rate, RATE.MULTIPLIER, in the prototype is a fractional multiplier applied to the specific type of equipment emplacing the obstacle. For instance, a M128 Ground Emplaced Mine Scattering System (GEMSS) can on average lay, say, 800 antitank (AT) mines an hour. The AT minefield in Figure 15 requires 550 AT mines. Using Equation (1) below, one GEMSS working in unopposed conditions can lay all of the AT mines in this prototype in 0.69 hours in flat terrain (TERRAIN.TPYE 1) or in 1.15 hours in mountainous terrain (TERRAIN.TYPE 3). Note that these are average hourly equipment work rates. Additional restrictions can be applied to account for equipment "down time" for maintenance or breakdowns. Logistical supply constraints should also be applied to equipment work rates upon completion of the JWAEP logistics functional area model [Ref. 9].

$$CompTime = \left(\frac{NumAT\min es}{(EquipRateAT\min es / Hr)(RateMultiplier)} \right) \qquad (1)$$

2. Obstacle Complex Class Data

Obstacle complex class data are used to provide information describing specific obstacle types. They contain the general characteristics of an obstacle complex, which is inherited by every instance of that object in the model. These data are used to describe fields such as the obstacle icon, its controlling side (red or blue), location, and the individual obstacle or obstacles contained in the complex. Figure 16 illustrates an obstacle complex that might be used to block the movement of a mechanized enemy force. The frontage of the complex is assumed to be as big as the largest obstacle prototype contained in the complex. In this example, the block prototype, ID 801, has a 500 meter

front which determines the complex frontage. The complex depth is determined by adding the depth of all of its prototypes. Using this method to calculate depth also assumes that all prototypes are arrayed sequentially throughout the depth of the complex. The NUM.PROTOTYPES field provides the number of prototypes contained in the complex. The last field, PROTOTYPES, lists the sequence of obstacle prototypes contained in the complex.

```
1081    "BLOCK Complex Type A"
  SIDE. . .FRONTAGE. . . . .DEPTH. . . . . . . .NUM.PROTOTYPES
    1          500              640                      3
        PROTOTYPES
                ID. . . . . . . .NAME. . . . . . . . . . . . . . . . . QTY
                801          "Block Minefield"                   1
                806           "Antitank Ditch"                   1
                801          "Block Minefield"                   1
        END.PROTOTYPES
```

Figure 16. An Obstacle Complex Prototype

3. Obstacle Complex Instances

Instances of an obstacle complex enable a model user to quickly develop a barrier plan of tactical obstacles over the entire theater. These instances can be used for modeling several phases of a campaign. Obstacle complex instance data define all of the various obstacle complexes that are specific to a particular scenario in JWAEP. These input data are contained in a new file called "*complex.dat*".

Each instance of an obstacle complex has several parameters that uniquely define it. These are the complex number, center of mass location, and its vertices. Figure 17 illustrates a BLOCK obstacle complex instance. The center of mass field, CENTER.MASS, is used for engineer travel calculations and is expressed as a Universal Transverse Mercator (UTM) grid coordinate or longitude/latitude. Vertices depict the boundary of the complex and are entered in a clock-wise or counter clock-wise fashion, similar to the center of mass field. Possible obstacle complex orders are INITIALIZE, and

EMPLACER. Similar to unit orders, the INITIALIZE order is the first order for all complex instances. It specifies the location and delta time the complex enters a scenario. The initialize order for a complex has one additional field, STRENGTH, that identifies the initial decimal percent strength for the complex. In Figure 17 the initialize order for this complex is 1.0, or maximum strength upon initialization. In the Korean MRC scenario this may represent one of the many existing obstacles in the barrier plan along the demilitarized zone (DMZ). The other type of order, EMPLACER, has a field for the particular unit responsible for emplacing this complex. Emplacer orders represent complexes that are preplanned and partially complete or only preplanned. This type of scripted order stream may account for most , if not all, of the preplanned tactical obstacles that comprise the theater barrier plan.

```
COMPLEX.ID
      5001      "BLOCK Complex for Armored Unit"
  CENTER.MASS . . .VERTICES
    UT34684497     UT34184697  UT35184697  UT 35184387  UT34184297

ORDERS
        DELTA.TIME. .. . . .TYPE
                0.0             INITIALIZE          UT34684497       1.0
END.ORDERS
```

Figure 17. Obstacle Complex Instance

IV. LOGIC FOR UNIT AND OBSTACLE ENCOUNTERS

Chapter III provided a structure for representing engineers and obstacles. This chapter provides a review of the JWAEP attrition methodology, introduces the Army's obstacle breaching theory and tactics, and describes the three unit/obstacle interactions modeled. Next, it describes the unit delay and attrition for obstacle complex encounters and the situations when ATCAL or the JWAEP engineer module handles adjudication. This chapter also briefly discusses the additional refinements necessary for unit path selection using the model's automatic path generator. Finally, the JWAEP engineer strength parameters are discussed and applied as a decision mechanism for allocating engineer support to combat units.

A. GROUND CLOSE COMBAT ATTRITION IN JWAEP

It is necessary to review the JWAEP ground attrition methodology before discussing unit and obstacle encounters. Ground close combat attrition calculations used in the JWAEP simulation are performed by the Attrition Calibration (ATCAL) model, developed at the US Army Concepts Analysis Agency (USACAA), and used at USACAA and the USAF Studies and Analysis Center[1]. ATCAL supporting data are maintained in the "*wpnvseq.dat*" file.[Ref. 2]

1. The JWAEP Adjudication Cycle

The cycle of adjudication indicates how frequently the equipment losses and relative force ratios are computed in JWAEP. In the absence of a trigger event, the status of the battle is computed every 12 hours. This is the default value and can be changed by the user. However, the data are normally based on a 12 hour cycle. The attrition adjudication process performed by ATCAL determines the expected strength and movement of forces at the end of a cycle, based on force ratios and unit postures. Events

[1] ATCAL has also been integrated into other models such as TACWAR.

that trigger adjudication before the end of a 12 hour cycle cause attrition to be based on a linear fraction of the full 12 hour cycle.[Ref. 2]

2. Close Combat And Adjudication

Ground close combat is triggered when a friendly force enters an enemy occupied node or upon encountering the enemy while traversing an arc. JWAEP distinguishes arc and node combat differently because their geometry is different within the model. The adjudication process for both cases is handled by ATCAL using different input parameters.[Ref. 2]

3. ATCAL

ATCAL is an aggregated attrition model. It consists of a number of equations which can be used to compute attrition, whenever values for several input parameters (provided by JWAEP) are known. These same equations can be used "backwards" to derive values for the parameters from the output of a higher resolution division level model called the Combat Sample Generator (COSAGE). The attrition equations in ATCAL are heterogeneous and compute casualties for firer-target pairings by weapon system type. The two basic attrition equations are for point fire and area fire. The ATCAL model does not step through time; instead it computes the casualties for an entire force-on-force engagement at once. ATCAL uses an iterative attrition computation procedure, checking each iteration to see if it has achieved a user specified convergence level. Its primary output is a killer-victim (KV) scoreboard that details the results of the attrition equations. The KV scoreboard shows casualties to type k systems inflicted by system type i using weapon type j (expressed simply as system (i,j)). JWAEP uses these KV scoreboards to assess attrition for all ground battles.[Ref. 10: p. 134-138]

4. COSAGE Limitations

ATCAL "calibrates" attrition in JWAEP to the results of a similar battle simulated in COSAGE. However, the COSAGE high resolution division battle has some limitations

in the type of weapon systems it represents. For instance, it does not represent long range artillery or air defense fires. These weapon systems are not organic to a division but are often found in the theater of operations in support of division operations. COSAGE also does not represent most of the weapons systems of other services that are commonly associated with joint warfare (that may or may not be a part of a division battle). For example, it has a limited capability for representing close air support (CAS) and does not model any other type of USAF air support. Additionally, COSAGE does not represent naval surface fire support (NSFS) which is an increasingly likely factor in the realm of littoral warfare.

B. OBSTACLE BREACHING THEORY AND TACTICS

Obstacle breaching is defined as the employment of a combination of tactics and techniques to project combat power to the far side of an obstacle. It is also perhaps the single most difficult combat task required of a maneuver force. Maneuver forces employ five types of breaching operations: the bypass, in-stride, deliberate, assault, and covert breaches. Forces that encounter an obstacle either extract themselves using organic methods or conduct a breaching operation. For instance, an armored unit that encounters a minefield may choose to use its organic tank-mounted plows or call upon its engineer support to conduct an in-stride breach. [Ref. 11: p. 2-1]

The bypass tactic is used when it is not essential to maintain momentum. It is used to avoid the entire obstacle and results in a change in the unit's direction of movement. The in-stride breach aims to minimize losses while maintaining the momentum of an attack. It is used by maneuver brigades and task forces to quickly overcome unexpected or lightly defended tactical obstacles. The deliberate breach is a scheme of maneuver specifically designed to cross an obstacle in order to continue a mission. The deliberate breach is characterized by thorough reconnaissance, detailed planning, extensive preparation, and explicit rehearsal. A unit may conduct a deliberate breaching operation when it has failed in an in-stride breach attempt or believes that the enemy force ratio is

beyond using any other breach operation. The assault breach allows a force to penetrate an enemy's tactical and protective obstacles to destroy the defender in detail. The assault breach is conducted by company/team or platoon sized organizations. The covert breach is usually performed by light forces in order to protect its force from enemy fires. It is characterized by stealth, surprise, and a final assault with overwhelming force. Light forces silently perform covert breaches with dismounted forces during periods of limited visibility in order to minimize causalities and achieve surprise.[Ref. 11]

A unit may take another possible course of action and "bull through" or force its way through the obstacle without using a breaching operation. This action is attempted whenever it is necessary to maintain the momentum of an attack or speed of withdrawal/retrograde at all costs. The "bulling through" action is a desperate decision made when a commander has to act immediately to extricate his force from an untenable position within an obstacle when no other breaching operations are possible. It is not considered a breaching operation. For example, a bull through occurs when a maneuver unit is in a minefield receiving heavy fires and taking heavy losses and decides to force its way through the minefield rather that wait to conduct a breach or withdraw.[Ref. 11]

C. UNIT AND OBSTACLE INTERACTIONS MODELED

One action and two breaching tactics are modeled as explicit actions outside of ATCAL. They are the bull-through action and the bypass and in-stride breaches. These three actions are the most representative and appropriate for explicit representation considering the low level of resolution in JWAEP.

The other breaching tactics not modeled are best represented in high resolution COSAGE runs used as a baseline in the ATCAL attrition adjudication process. The covert breach is a high resolution action, performed by dismounted forces at the company team or the platoon level. Explicitly modeling this type of breach outside of ATCAL is not appropriate to the low resolution present in JWAEP. Additionally, the deliberate

breach and accompanying battle is probably best represented as an intense defense posture using ATCAL, not in a separate attrition mechanism in JWAEP.

D. OBSTACLE TACTIC INSTEAD OF MINEFIELD TACTIC

The term obstacle breaching tactic is more general than the often used term minefield breaching tactic. Unit encounters with a minefield probably result in both attrition and delay of movement. On the other hand, an encounter with an AT ditch most likely delays, unless it is employed with a minefield.[2] An obstacle complex can consist of any number and/or type of obstacle prototypes that cause attrition, delay, or both attrition and delay. Modeling the more generic obstacle tactic decision logic allows JWAEP to call the same procedure for the attrition and/or delay for any type of obstacle prototype or complex.

E. OBSTACLE COMPLEX ATTRITION AND DELAY ALGORITHMS

The attrition and delay assessed a unit depends primarily on the type of obstacle complex encountered, the size of the complex relative to the encountering unit, and the tactic employed by the unit to overcome the complex (the reader is reminded here that complex size is a function of the single largest obstacle prototype frontage and combined depth of all of the prototypes). The tactic employed by a unit depends on the type of unit and its posture when encountering an obstacle. In general, non-engaged units (units that are not currently in a battle) will bypass known complexes when possible. Engaged units, or units with orders to attack, may decide to employ some type of aggressive breaching tactic. For example, an armored brigade in an administrative convoy most likely prefers to bypass a minefield whereas this same unit may opt to conduct an in-stride breach during an attack.

---

[2] In both cases, a force overwatching these obstacles will try to use direct and indirect fires to cause attrition whenever its weapons systems are within range.

The assumptions applicable for the methodology used in the attrition and delay algorithms are as follows:

- When a unit encounters an obstacle complex and is targeted by direct and/or indirect fires (that are modeled in COSAGE), this combat is passed to ATCAL for adjudication using modified input parameters.

- For a given unit size and type, the delay and attrition assessed by an individual obstacle have constant values[3].

- The attrition and delay caused by an obstacle complex is the sum of the (independent) attrition and delay caused by each obstacle prototype in the complex.

- A unit formation is approximated by a rectangle whose length and width varies according to the size, type, and posture of that unit.

- A unit's equipment is uniformly distributed throughout its formation.

1. Discovery Losses And Delay

Upon encountering an undiscovered complex a unit suffers some initial discovery losses, abbreviated DL. These losses are scaled by the fraction of the unit encountering the complex. Figure 18 illustrates three cases of the geometry used to determine this fraction. This unit also incurs a discovery delay, DD, while making a decision on what tactic to employ and while setting that tactic in motion.

---

[3] This methodology can accommodate random variables when information on their distributions is known.

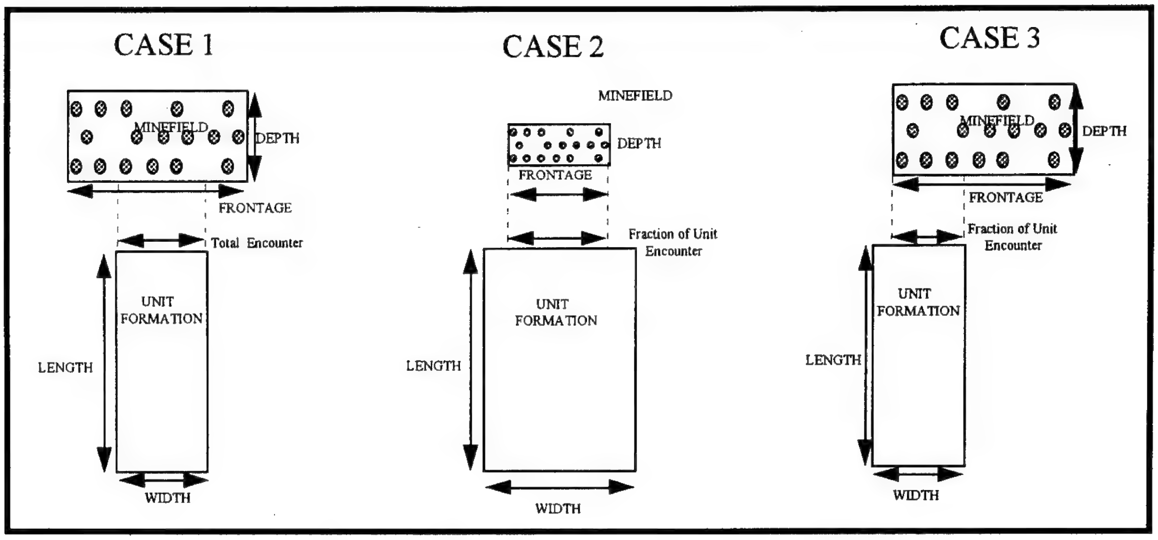

Figure 18. Geometry of a Unit and Obstacle Encounter

2. Crossing Losses And Delay

If a unit decides to cross an obstacle it must conduct an in-stride breach or bull-through of the complex, suffering additional crossing losses (IL or BL losses, respectively) and a crossing delay (ID or BD). In general, bull through losses are greater than in-stride breach losses for a given unit and obstacle.

3. Bypass Delay

If the decision is to bypass the complex, a bypass delay, AD, occurs while the unit searches for a route around the minefield and then actually moves around it. The bypass delay time is computed as the distance around the complex divided by the fraction of the current unit speed.

4. Total Losses And Delay

The total attrition and delay assessed a unit are computed by summing all of the attrition and delay components over all obstacle prototypes contained in the complex. The total delay applies to the entire unit, whereas the attrition losses are expressed in terms of losses for each type of equipment in the unit. Note that the total losses and delay

described above are caused solely by the obstacle and assume there are no direct or indirect fires present.

5. An Example Of The Delay And Loss Process

A simple example serves to convey the delay and loss process. Assume that an armor battalion encounters an obstacle complex composed of a single AT minefield prototype. Also assume that this is the first unit encounter of any kind for this complex, so the complex is at full strength. The armor battalion suffers discovery losses (determined using the fraction of the unit frontage that encounters the complex) and a discovery delay on initial contact. The lead element may decide to conduct an in-stride breach using a mine clearing line charge (MICLIC). The vehicle equipped with a MICLIC does not normally travel in the front of an attack formation so there is a delay while this vehicle moves to the front of the unit formation and deploys its explosive clearing charge. Once the MICLIC "clears" a path through the complex, the unit proceeds through the breach where it may suffer crossing loses and a crossing delay. The total delay time incurred by the unit is the sum of the discovery and in-stride breach delays (TD = DD + ID). Similarly, the total attrition is the sum of discovery losses and in-stride breach losses (TL = DL + IL) for each type of equipment in the unit. The obstacle complex, now partially cleared, has its effectiveness reduced by a fractional amount proportional to the unit area traversed compared to the total complex size. At this time the model also updates the perception about the node or arc to reflect the obstacle complex and its reduced effectiveness (amount cleared).

6. Delay Calculations

Equation (2) represents the total delay assessed a unit when it encounters an obstacle complex. This represents the sum of the delay time caused by each obstacle prototype contained in the complex. Note that for any type tactic employed, only two of the four summations are evaluated. In the example above, where the unit uses a MICLIC to breach the complex, only the DD and ID summations apply. These two summations

represent the discovery and in-stride breaching delays for the complex composed of one AT minefield prototype (*n* = *1*).

$$TD = \sum_{j=1}^{n} DD_j + \sum_{j=1}^{n} ID_j + \sum_{j=1}^{n} BD_j + \sum_{j=1}^{n} AD_j \tag{2}$$

where,

TD = the total delay assessed a unit in an obstacle complex;

DD_j = the discovery delay for obstacle prototype *j*, where *j* = *1*, ..., *n* prototypes present in the complex;

ID_j = the in-stride breach delay for obstacle prototype *j*, where *j* = *1*, ..., *n*;

BD_j = the bull-through breach delay for obstacle prototype *j*, where *j* = *1*, ..., *n*;

AD_j = the bypass delay for obstacle prototype *j*, where *j* = *1*, ..., *n*.

The individual delay calculations used in Equation (2) are computed as either a time delay or the difference between the current unit speed and the reduced unit speed caused by a particular obstacle prototype. The delays associated with a particular obstacle prototype are expressed for each type of unit category and size in JWAEP. The discovery delay, DD, is expressed as a time delay, in decimal hours. All other delays are expressed as a fraction of the current unit speed for the particular action attempted (bypass, in-stride, and bull-through). Figure 19 illustrates a sample delay data file for a brigade size Armor/Mech unit. Some additional information is also included in this data file. These items are the fraction cleared (FRAC.CLEARED), the ineffectiveness point (INEFF.PT), and ineffectiveness time (INEFF.TIME) for each prototype. The fraction cleared represents the fractional reduction in the effectiveness of the obstacle caused by a single unit crossing. The ineffectiveness point is the threshold, expressed as a percentage, where the obstacle is no longer effective and is removed from the network. The ineffectiveness time is the duration, expressed in days, when the obstacle is no longer effective. This time accounts for minefields emplaced with self-destruct times. An ineffectiveness time of "0" indicates that the obstacle never becomes ineffective in and of itself.

```
@ A= Bypass
@ B= In-Stride
@ C= Bull-Through
UNIT.CATEGORY
   ID . . . . .NAME
   1001      "Armor/Mech"
UNIT.SIZE
   ID . . . . .NAME
   1004    "Brigade"
 PROTOTYPE
ID . . . .NAME. . . . . DD(HRS). . .FRAC.SPEED. . FRAC.CLEARED. .INEFF.PT . .INEFF.TIME(DAY)
                                    A    B    C     A    B    C
801  "AT Minefield"       .25       .9   .5   .7    0    .6   .5       .8              2.0
802  "AP Minefield"       .25       .9   .5   .7    0    0    0        .8              1.5
803  "Mixed Minefield"    .25       .9   .5   .7    0    0    0        .8              2.0
804  "Dummy Minefield"    .25       .9   .8   .85   0    1    1        .99             0
806  "Anti-Tank Ditch"    .17       .9   .5   .7    0    1    .5       .8              0
 .      .                 .         .    .    .     .    .    .        .               .
 .      .                 .         .    .    .     .    .    .        .               .
 .      .                 .         .    .    .     .    .    .        .               .
```

Figure 19. Obstacle Prototype Delay And Effectiveness Data

7. Attrition Calculations

Equation (3) represents the total attrition assessed for equipment type i when a unit encounters an obstacle complex. Similar to the delay equation above, only two of the four separate summations are ever evaluated. In the example above, where the unit uses a MICLIC to breach a complex, only the DL and IL summations apply.

$$TL_i = \left\{ \sum_{j=1}^{n} DL_j + \sum_{j=1}^{n} IL_j + \sum_{j=1}^{n} BL_j \right\} \bullet \mathrm{FR} \qquad (3)$$

where,

TL_i = the total losses assessed a unit for equipment type i in an obstacle complex;

DL_j = the discovery losses for obstacle prototype j, where $j = 1, ..., n$ prototypes present in the complex;

IL_j = the in-stride breach losses for obstacle prototype j, where $j = 1, ..., n$;

BL_j = the bull-through breach losses for obstacle prototype j, where $j = 1, ..., n$;

FR = the fraction of the unit exposed to the complex.

The fraction of the unit exposed to the complex, FR, is expressed in Equation (4). This expression accounts for all of the cases possible in an encounter as illustrated in Figure 18.

$$FR = \left(\frac{Unit\ Frontage\ Overlap\ With\ Obstacle}{Total\ Unit\ Frontage} \right) \tag{4}$$

A data file similar to Figure 20 contains the obstacle effectiveness data for each type of equipment lost in an obstacle encounter. These losses are expressed as the number of equipment losses per unit formation per mine per meter frontage of the obstacle. This standard expression for representing losses enables the model to assess losses for a given unit in any type of formation (e.g., move to contact, attack, and tactical convoy) that encounters a minefield of one mine per meter frontage. The one mine per meter frontage expression is also a standard measure for minefield density. This method assumes that losses are linearly proportional over all unit formations and minefield densities. For instance, the equipment losses for a brigade sized unit in a movement to contact formation encountering a 1.5 density minefield (1.5 mines per meter frontage) are 1.5 times the amount produced by the standard 1.0 density minefield.

```
UNIT TYPE = ARMORED/MECH
UNIT SIZE = BATTALION
UNIT FORMATION = MOVEMENT TO CONTACT
@  A= Discovery Losses
@  B= In-Stride Breach Losses
@  C= Bull-Through Losses
 EQUIPMENT                         PROTOTYPE ID NUMBER
ID . . . . .NAME. . . . . . . . . . . . . . . . . . . . .801. . . . . . . . . . . . . .802.. . . . . . . . . . . . . . 803. . . . . . . .
                               A   B   C      A   B   C       A   B   C
1110    (M1A1 Tank)            0   0   1      0   0   0       0   0   1
1200    (M2 IFV)               0   1   2      0   0   0       0   0   1
1210    (ITV)                  0   1   2      0   0   0       0   0   1
 .       .                     .   .   .      .   .   .       .   .   .
 .       .                     .   .   .      .   .   .       .   .   .
 .       .                     .   .   .      .   .   .       .   .   .
```

Figure 20. Equipment Losses Assessed For Each Obstacle Prototype

F. USING IMPLICIT OR EXPLICIT OBSTACLE ATTRITION

Decision rules must be outlined to determine when to use the implicit (ATCAL) or the new explicit obstacle attrition methodology in JWAEP. As discussed earlier, ATCAL handles all ground close combat attrition in JWAEP. When a trigger event occurs, all of the necessary battle parameters are passed to ATCAL for adjudication. From the JWAEP model perspective, this is an implicit way of handling attrition.

Implicit ATCAL attrition is appropriate whenever a maneuver unit encounters an obstacle complex in a close combat situation. A close combat engagement occurs when two units are within physical proximity to each other. The model determines the physical proximity for close combat by keeping track of a center-of-mass parameter for each unit. Direct fire weapons, indirect artillery fires (e.g., organic, general support, or reinforcing), close air support (CAS), and tactical obstacles that are part of a maneuver force can all be represented in a close combat engagement in ATCAL. However, it is vital for ATCAL to have a robust library of COSAGE run results in order to adequately approximate the close combat engagement conditions in JWAEP. Given a COSAGE run with similar conditions to the JWAEP close combat engagement, ATCAL will accurately calibrate attrition.

Explicit obstacle attrition is appropriate whenever a unit encounters a complex and is not in a direct fire engagement or receiving indirect fires modeled in the close combat engagement. This includes all indirect fires such as General Support (GS) artillery fires and missiles, aircraft delivered fires such as battlefield air interdiction (BAI), and naval surface fire support (NSFS). Explicit obstacle attrition may also be used if the COSAGE library does not contain similar run for the current engagement situation in JWAEP.

G. UNIT MOVEMENT BY THE AUTOMATIC PATH GENERATOR

The JWAEP default behavior for determining unit movement routes, thereby allowing a unit to carry out assigned orders, is to invoke the automatic path generator. The

automatic path generator logic in JWAEP must be modified to account for non-engaged unit movement over a network containing obstacle complexes. This generator uses a Dykstra's algorithm which applies a cost function to each possible route. The generator selects the least cost path, of all possible paths, to the destination node. In general, the cost associated with a path is a function of the time necessary to traverse that path and the estimated attrition from perceived enemy units on the path. Time is dependent on the arc terrain, the unit category and size, and the unit formation. Attrition is based on a unit's perceived attrition on a particular path. The cost of traversing an arc is modified depending on the order a unit is planning to carry out. For instance, enemy controlled arcs or nodes have an infinite cost for a unit planning an administrative march.

This cost function has to be modified to account for obstacle complexes when a unit is aware of their existence. An estimate of this additional cost can be easily calculated using the attrition and delay algorithms described earlier. These calculations are based on the friendly unit's perception of the strength of an obstacle complex (not necessarily on its actual or "ground truth" strength) and the unit's mobility strength.

H. ENGINEER STRENGTH PARAMETERS IN JWAEP

Several different strength parameters are proposed for describing the aggregated strength of a unit in JWAEP. These strength parameters are grouped according to Attrition, C^3I, Mobility, and Logistics. The Mobility Strength Group (MSG) includes parameters for a unit's Mobility Strength (MMO) and Countermobility Strength (MCM). MMO provides an estimate of a unit's ability to overcome tactical obstacles and MCM estimates a unit's potential for emplacing tactical obstacles. These strength parameters are intended to be used in the JWAEP decision making logic. They can be used in determining such things as route selection, friendly engineer support requirements, and enemy engineer potential.

1. Mobility Strength (MMO) Values

The MMO value is unique for each unit represented in a scenario. It is computed as the ratio of two values. For units with engineer assets, the first value, MEQ_{AUTHi}, represents the unit's authorized TO&E strength of a particular item of "mobility enhancing" equipment found in the engineer unit type definition. The second value, MEQ_{OHi}, represents the current on-hand quantities of this equipment present in the unit. Mobility enhancing equipment are items of equipment whose primary purpose facilitates friendly unit movement. These are items such as the Combat Engineer Vehicle (CEV), MICLIC, and Armored Vehicle Launched Bridge (AVLB). The MMO can either be expressed as a vector, representing all mobility equipment types in a unit, or as a scalar based on the sum of all the individual types of equipment. The scalar representation assumes that one type of mobility enhancing equipment is just as good as another unless weighted "values" are assigned for each type of equipment. It is best to use MMO as a scalar with weighted values when making decisions based on rule sets. The weight for a particular item of equipment, w_i, must provide logical results for the decision they are intended to make in the model. For instance, an AVLB should have a high mobility value for bridging a gap and little to no value in breaching a minefield. Equation (5) illustrates the MMO for a single item of equipment.

$$MMO_i = w_i\left(\frac{\mathrm{MEQ_{OHi}}}{\mathrm{MEQ_{AUTHi}}}\right) \tag{5}$$

2. Countermobility Strength (MCM) Values

MCM values are similar to MMO values. The first value, CEQ_{AUTHi}, represents the unit's authorized TO&E strength of a particular item of "countermobility enhancing" equipment found in the engineer unit type definition and CEQ_{OHi}, represents the current on-hand quantities. Countermobility enhancing equipment are items of equipment whose primary purpose facilitates tactical obstacle emplacement to hinder enemy unit movement.

These are items such as the VOLCANO, Ground Emplaced Mine Scattering System (GEMSS), and the D7 bulldozer. MCM is also expressed as a weighted scalar as shown in Equation (6).

$$MCM_i = w_i\left(\frac{\mathrm{CEQ}_{\mathrm{OH}i}}{\mathrm{CEQ}_{\mathrm{AUTH}i}}\right) \tag{6}$$

3. Accounting For Unit Size

The overall MMO and MCM values of a unit must also be multiplied by a constant value that accounts for the unit's size. This precludes situations where the MMO or MCM for a company and brigade are equal because these units have the same ratio of on-hand to authorized equipment. The unit size multipliers are illustrated in Table 3. These values are based on the relative size of one unit to the other. For instance, one battalion is normally composed of three line companies and one brigade is composed of three battalions. Using these unit size multipliers distinguishes the difference in magnitude of different sized units when comparing their MMO and MCM values.

UNIT SIZE	UNIT SIZE MULTIPLIER
Company	1
Battalion	3
Brigade	9
Division	27

Table 3. Unit Size Multipliers

I. ALLOCATING ENGINEER SUPPORT

The overall MCM strength of a unit is useful in determining where to allocate engineer units that are performing general support missions. Figure 21 illustrates a simple pseudocode decision algorithm that uses a unit's MCM strength in allocating engineer countermobility support. This simple example is intended to demonstrate how JWAEP can use MCM and MMO strength values as a tool in its decision making logic.

```
For All Friendly Cbt Units_i {
        IF{  (MCM < VALUE_SPECIFIED) AND (ORDERS = DEFEND Or DELAY)
        Add Cbt Unit_i to Candidate for Engr CM Supt List   }
For All Friendly Cbt Units on CM List{
        SORT CM List so that  (MCM Unit_i <= MCM Unit_i+1)  for all Cbt Units on List)
        For All Uncommitted Engr Units{
                IF{ ( (Engr Travel Time  + Work Time) < Cbt Unit_i Msn Start Time)
                        Add Engr Unit to Supt Cbt Unit_i List      }
        SORT Supt Cbt Unit_i  List so that (MCM Unit_i >= MCM Unit_i+1)for all Engr Units on List)
        Assign Engr Unit_1 CM Supt Msn for Cbt Unit_1
        REMOVE ENGR Unit_1 AND Cbt Unit_1  From Both Lists          }
```

Figure 21. Pseudocode For Engineer Countermobility Support

J. CREATING SITUATIONAL OBSTACLES

Using obstacle complex structures, a scenario developer can create obstacle instances over the entire battlefield throughout several phases of a campaign. However, JWAEP must also have some decision logic rules in order to create obstacles in response to the developing situation in a particular scenario. This logic can be based on the model's course of action (COA) perception. For instance, a scenario developer can create several barrier plans, each of which are tailored for a particular COA. During a model run, a particular barrier plan is executed when the perceived COA reaches a user specified threshold. This logic must also be sensitive to the engineer work and time requirements for emplacing a particular barrier plan. In some situations where the COA threshold is never reached, the model must execute the "best" barrier plan based on the amount of engineer assets available and remaining time before expected enemy contact.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This research developed the structures for modeling obstacles and engineer forces in a theater level combat model. It focused on identifying the pertinent aspects necessary to portray obstacles and engineers in a low resolution model. This work concentrated on modeling tasks in the engineer functional area of countermobility. It identified engineer units to model and defined their data structures for use in JWAEP. The types and quantities of engineer equipment are used to represent the way in which engineer forces accomplish missions in their functional areas. Additionally, obstacle structures were designed in a way that permits model users to represent aggregations of tactical obstacles at a comparable level of resolution with combat units. Both of these structures efficiently capture the essential characteristics necessary in a theater level model, without causing unacceptable increases in memory or computing requirements.

The logic for unit and obstacle encounters is also modeled. The bypass breach, in-stride breach, and bull-through action are modeled as explicit actions outside of ATCAL close combat engagements. The attrition and delay algorithms for these actions allow JWAEP additional flexibility in modeling the effects of weapons such as long range GS artillery fires, battlefield air interdiction (BAI), and naval surface fire support (NSFS) that are not part of an ATCAL close combat engagement. Last of all, engineer strength parameters are defined and shown how they can be used in the JWAEP decision making logic.

This work is unlike other research in this area for several reasons. Unlike earlier modeling efforts in the engineer community, this approach does not attempt to nest a high resolution engineer module within a low resolution theater level model. Instead, it uses the minimal essential elements necessary to captures the effect of engineers and obstacles

on the battlefield. This research is also unique in its object oriented approach for representing obstacle complex structures. Some theater level models ignore the effects of tactical obstacles all together because of the aggregated unit and individual obstacle resolution mismatch. Other theater level models represent tactical obstacles as part of the existing battlefield, terrain or network. This method forces model designers to use a dynamic battlefield that changes frequently or periodically throughout the course of a simulation. A frequent battlefield update cycle causes an enormous increase in computing requirements, whereas a less frequent update cycle causes some loss in realism between unit and obstacle interactions. The object oriented obstacle structures in this research are not a part of the existing network. This permits scenario developers to quickly build and place obstacle complex structures anywhere on the existing battlefield or network. Additionally, unit and obstacle encounters are resolved separately so there is no need for a dynamic network or update cycle.

B. RECOMMENDATIONS

This research is the first effort to incorporate obstacles and engineers in JWAEP. There are several additional topics to expand upon and explore in both obstacle representation and the engineer functional areas.

1. Extensions Of The Basic Engineer Structure

The engineer functional areas of mobility and survivability should be incorporated in the engineer module. Ongoing research in the mobility area is focused on the process for detecting obstacles and making tactical and operational decisions based on this information (perception) [Ref. 12]. A methodology for representing the essential tasks in survivability should also be added to JWAEP. Once these two areas are defined and working in the model, analysis should be performed to determine how to best employ engineer units. For instance, engineers are called upon to perform both countermobility and survivability tasks during preparations for a defense. A methodology is needed to

determine what combination of countermobility and survivability tasks is optimal for a given situation.

It is not possible to represent sustainment engineering tasks such as maintenance and repair of a main supply route (MSR) in the current network representation of the battlefield. The arc and node network in the JWAEP is not affected by unit movements or engagements. The additional computing requirements needed to convert to a dynamic network are probably outweighed by any need to represent enhanced or degraded unit movement.

2. Logistical Constraints For Obstacle Emplacement

Currently, there is no logistical constraint on the obstacle emplacement capability of engineer units. Once the logistical network is in place, barrier materials, such as mines, should be constrained by local availability and transport capabilities.

3. Targeting Units That Encounter An Obstacle Complex

A methodology should be developed to target enemy units when they encounter an obstacle complex. Named areas of interest (NAIs) should be located near each obstacle complex and a target area of interest (TAI) should be placed on top of each complex. When an enemy unit crosses a NAI, friendly units are alerted and target fires on the unit when it reaches the TAI (obstacle complex). This methodology allows friendly units to target the enemy with any assortment of available fires.

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14.	US Army War College Center for Strategic Leadership ATTN: COL Wilkes Bldg 650 Carlisle Barracks, PA 17013-5050	1
15.	The Joint Staff - J6AC ATTN: John Garstka 6000 The Joint Staff Washington, DC 20318-6000	1
16.	Center for Naval Warfare Studies Naval War College Newport, RI 02841	1
17.	US Army Missile Command ATTN: AMSMI-RD-AC (Dr. Fowler) Redstone Arsenal, AL 35898-5242	1
18.	US Army Materiel Systems Analysis Activity ATTN: Mr Bill Clay Aberdeen Proving Ground, MD 21005-5001	1
19.	CPT Brian Hobson 5262 Access Road Dayton, Ohio 45431	1